LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

LLNL-TR-418583

NDCX-II project commencing at LBNL

A. Friedman, J. Kwan

October 23, 2009

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

NDCX-II project commencing at LBNL

Alex Friedman, LLNL, and Joe Kwan, LBNL

Earlier this year, the U.S. Department of Energy Office of Fusion Energy Sciences approved the NDCX-II project, a second-generation Neutralized Drift Compression eXperiment. NDCX-II is a collaborative effort of scientists and engineers from Lawrence Berkeley National Laboratory (LBNL), Lawrence Livermore National Laboratory (LLNL), and the Princeton Plasma Physics Laboratory (PPPL), in a formal collaboration known as the Virtual National Laboratory for Heavy Ion Fusion Science (HIFS-VNL). Supported by $11 M of funding from the American Recovery and Reinvestment Act, construction at LBNL commenced in July of 2009, with completion anticipated in March of 2012.

Applications of this facility will include studies of: the basic physics of the poorly understood "warm dense matter" regime of temperatures around 1 eV and densities near solid, using uniform, volumetric ion heating of thin foil targets; ion energy coupling into an ablating plasma (such as that which occurs in an inertial fusion target) using beams with time-varying kinetic energy; space-charge-dominated ion beam dynamics; and beam focusing and pulse compression in neutralizing plasma. The machine will complement facilities at GSI in Darmstadt, Germany, but will employ lower ion kinetic energies and commensurately shorter stopping ranges in matter.

Much of this research will contribute directly toward the collaboration's ultimate goal of electric power production via heavy-ion beam-driven inertial confinement fusion ("Heavy-Ion Fusion," or HIF). In inertial fusion, a target containing fusion fuel is heated by energetic "driver" beams, and undergoes a miniature thermonuclear explosion. Currently the largest U.S. research program in inertial confinement is at Livermore's National Ignition Facility (NIF), a multibillion-dollar, stadium-sized laser facility optimized for studying physics issues relevant to nuclear stockpile stewardship. Nonetheless, NIF is expected to establish the fundamental feasibility of fusion ignition on the laboratory scale, and thus advance this approach to fusion energy. Heavy ion accelerators have a number of attributes (such as efficiency, longevity, and use of magnetic fields for final focusing) that make them attractive candidates as Inertial Fusion energy (IFE) drivers [1]

As with LBNL's existing NDCX-I, the new machine will produce short ion pulses using the technique of neutralized drift compression. A head-to-tail velocity gradient is imparted to the beam, which then shortens as it drifts in neutralizing plasma that suppresses space-charge forces. NDCX-II will make extensive use of induction cells and other hardware from the decommissioned ATA facility at LLNL. Figure (1) shows the layout of the facility, to be sited in LBNL's Building 58 alongside the existing NDCX-I apparatus.

This second-generation facility represents a significant upgrade from the existing NDCX-I. It will be extensible and reconfigurable; in the configuration that has received the most emphasis, each NDCX-II pulse will deliver 30 nC of ions at 3 MeV into a mm-scale spot onto a thin-foil target. Pulse compression to ~ 1 ns occurs in the accelerator as well as in the drift compression line; the beam is manipulated using suitably tailored voltage waveforms in the accelerating gaps.

NDCX-II employs novel beam dynamics. To use the 200 kV Blumlein power supplies from ATA (blue cylinders in the figure), the pulse duration must first be reduced to less than 70 ns. This shortening is accomplished in an initial stage of non-neutral drift compression, downstream of the injector and the first few induction cells. The compression is sufficiently rapid that fewer than ten long-pulse waveform generators are needed, with Blumleins powering the rest of the acceleration.

Extensive simulation studies have enabled an attractive physics design [2-4]; these employ both a new 1-D code (ASP) and the VNL's workhorse 2-D/3-D code Warp. Snapshots from a simulation movie (available online [5]) appear in Fig. 2.

Studies [6] on a dedicated test stand are quantifying the performance of the ATA hardware and of pulsed solenoids that will provide transverse beam confinement (ions require much stronger fields than the electrons accelerated by ATA).

For more information, see the recent article in the Berkeley Lab News [1] and references therein. Joe Kwan is the NDCX-II project manager and Alex Friedman is the leader for the physics design.

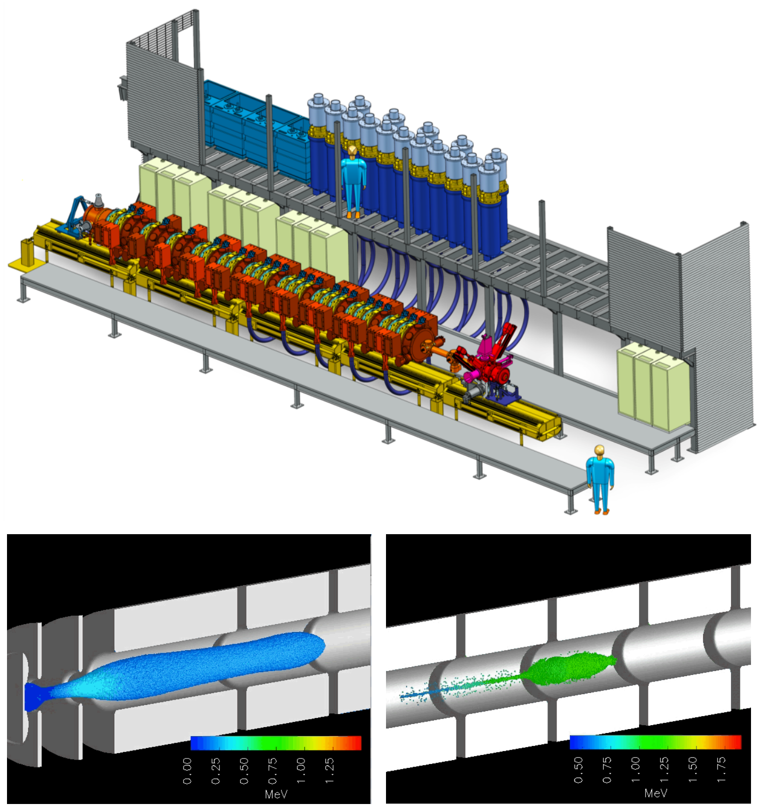

Figure 1. (top) Computer-aided-design rendering of NDCX-II. The ion source and injector are at the left; voltage sources (blue) reside on a mezzanine; the induction cells are in yellow-orange; and the drift-compression line and target chamber are at the right. (bottom) Images from a 3-D particle-in-cell simulation of NDCX-II using the Warp code, showing beam as it exits injector and partway through machine.

[1] http://newscenter.lbl.gov/feature-stories/2009/10/14/warm-dense-matter

[2] A. Friedman *et al.*, Nucl. Instr. and Meth. A **606**, 6 (2009).

[3] W. M. Sharp *et al.*, Proc. 2009 Particle Accel. Conf., http://hifweb.lbl.gov/public/papers/Sharp-PAC09ms.pdf

[4] A. Friedman *et al.*, Proc. 2009 Int'l. Comput. Accel. Conf., http://hifweb.lbl.gov/public/ICAP09/TH1IOpk04.pdf

[5] http://hifweb.lbl.gov/public/movies/ICAP09

[6] W. L. Waldron *et al.,* Fusion Sci. Technol. **56**, 452 (2009).

*This work was supported by the Director, Office of Science, Office of Fusion Energy Sciences, of the U.S. Department of Energy prepared by LBNL under Contract No. DE-AC02-05CH11231, by LLNL under Contract No. DE-AC52-07NA27344, and by Princeton Plasma Physics Laboratory under contract No. DE-AC02-76CH-O3073.